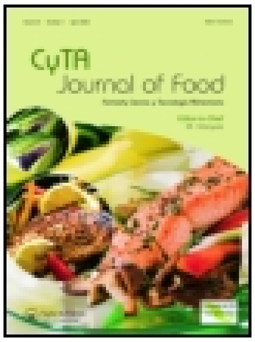

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Sustainable supply-chain: evolution of the quality characteristics of strawberries stored in green film packaging

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ABSTRACT

The use of green materials in the packaging can drive the choice of fresh fruits by the consumers. The objective of this study was to evaluate the suitability of green wrapping films for use in passive modified atmosphere packaging for the storage of strawberries (cv. Portola) for 7 days at 1 ± 1°C followed by an additional 2 days at 20 ± 1°C. One commercial polypropylene macro-perforated film (control) and three non-commercial biodegradable and compostable films (prototypes, Novamont, Novara, Italy) (films 1, 2 and 3) were used. The best headspace gas composition was obtained with film 1; a steady state was rapidly reached and this equilibrium was maintained for up to 5 days, with a composition of 17.60–18.50% O_2 and 5.30–5.60% CO_2. The sensorial evaluation of film 1 also yielded the best scores in terms of condensation, taste, marketability and redness of the fruits during shelf storage (at 20 ± 1°C).

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Films; modified atmosphere packaging; temperature; freshness quality; fruits storage

PALABRAS CLAVE
Plástico film; envasado con atmosfera modificada; temperatura; calidad de frescor; almacenamiento de fruta

Cadena de producción sostenible: evolución de las características cualitativas de las fresas almacenadas mediante envasado con plástico film ecológico

RESUMEN

La utilización de materiales ecológicos en el envasado puede ofrecer la elección de frutas frescas a los consumidores. El objetivo de este estudio fue evaluar el grado de sostenibilidad de los plásticos film para envasar en su utilización en el envasado con atmosfera modificada en el proceso de almacenamiento de las fresas (cv. Portola) durante 7 días a 1±1°C, seguido de 2 días adicionales a 20 ±1°C. Se utilizaron un plástico film comercial macroperforado de polipropileno (control) y tres plásticos film no comerciales biodegradables y aptos para abono (prototipos, Novamont, Novara, Italia) (film 1, film 2 y film 3). La mejor composición de gases se obtuvo con el film 1, con el cual se consiguió rápidamente un estado estable y ese equilibrio se mantuvo hasta 5 días, con una composición de 17,60-18,50% de O_2 y 5,30-5,60% de CO_2. La evaluación sensorial del film 1 también obtuvo el mejor rendimiento con las mejores puntuaciones en términos de condensación, sabor, comerciabilidad y rojez de los frutos durante el almacenamiento en estanterías (a 20±1°C).

Introduction

The prevention of spoilage and contamination, protection from mechanical damage, presentation of product information, convenience and facilitation of distribution throughout the supply chain are some of the most important purposes ascribed to food packaging (Wani, Singh, & Langowsky, 2014). Today, the attributes of choice for such packaging, especially for fresh products such as fruits, must satisfy various requirements related to the public good, and to this end, the use of green (renewable, degradable and recyclable) materials (Wu, 2012) could be a relevant and decisive advantage in the management and purchase of these products. The communication of the sustainability can represent a tool to bring out the fruit products from the anonymity, a strategy to make it 'remember', relying not only on the traditional values attributed to the segment, but also on a set of the supply chain attributes that can differentiate it. Although many developments in food packaging have been achieved over the past 20 years, the use of biomaterials and bioplastics remains limited to small scales and isolated facilities (Müller et al., 2014; Rhim, Park, & Ha, 2013; Tumwesigye, Montañez, & Oliveira, 2016). The improvement of sustainability through the adoption of a green supply chain and the use of materials from renewable resources is not easy, principally because of the different technological characteristics of these materials compared with the traditional ones (Jiménez, Fabra, & Talens, 2012). MAP is well known to improve the shelf life of highly perishable fresh fruits (Guillard et al., 2015; Wani, Singh, Gul, Wani, & Langowsky, 2014; Zhuang, Barth, & Cisneros-Zavallos, 2014), but few studies have addressed the optimization of the packaging atmosphere based on the matching of the gas permeation properties of different green films with the fruits to which they are best suited. Recently, Briano, Giuggioli, Girgenti and Peano (2015) and Giuggioli, Briano, Baudino and Peano (2015) evaluated the performance of biodegradable and compostable films for the MAP storage of raspberries and offered suggestions for their potential use depending on the changes in temperature throughout the supply chain. Strawberries are also products that are commonly considered as targets of MAP applications, primarily

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not only because of the short shelf life of these fruits due to their high susceptibility to mechanical injury, physiological disorders, water loss and decay (Peano, Girgenti, & Giuggioli, 2014; Peano, Giuggioli, & Girgenti, 2014) but also because of their widespread diffusion throughout the global market due to customer demand (Bhat, Geppert, Funken, & Stamminger, 2015). The improving of the storage life of strawberries fruits in MAP using plastic film is deeply studied and low O_2 concentrations (5–10 kPa) and high CO_2 concentrations (15–20 kPa) are the levels that should be achieved as suggested by different authors (Fonseca, Oliveira, & Brecht, 2002; Kader, 1993; Saltveit, 1993; Silva, Chau, Brecht, & Sargent, 1999). In this study, the properties of strawberry fruits packaged using three different biodegradable and compostable films were investigated after 7 days of storage at a temperature of 1 ± 1°C followed by 2 days of shelf storage at a temperature of 20 ± 1°C, which is the most common shelf temperature for produce at European retail outlets.

Materials and methods

Strawberry samples and storage conditions

Portola strawberries (*Fragaria × ananassa* Duch.) were harvested from a commercial orchard belonging to AgriFrutta Soc. Coop SRL (Peveragno, Cuneo, Italy) by trained pickers and quickly transported to a packing house facility cooled to 2°C (Peveragno, Cuneo, Italy). The fruits were selected for uniformity of size and colour development, and damaged strawberries were removed. The experimental trial began approximately 3 h after harvest. The samples were packaged in rigid PLA (polylactic acid) baskets (dimensions of 14.2 × 9.4 × 5 cm; consumer units), each containing 0.250 kg of fruit.

All samples (each set consisted of three baskets, for a total of 0.750 kg of fruit investigated at each time point) were hermetically wrapped using an electronic horizontal flow-pack wrapping machine (model Taurus 700, Delphin, Italy) equipped with a take-up reel with translational movement of the clamping jaws. One commercial polypropylene macro-perforated film (control, with 6-mm holes) (Trepack, Varese, Italy) and three non-commercial biodegradable and compostable films (prototypes, Novamont, Novara, Italy) (films 1, 2 and 3) were used to package the samples. The green films are from granules of corn starch blended at different concentrations produced by blown extrusion.

All samples were packaged under ordinary atmospheric conditions (0.2 kPa CO_2 and 21.2 kPa O_2), so, during the storage time, the passive MAP conditions inside each packages were developed due the interactions of the strawberries metabolism, the film permeability and the change of the storage temperature. The green films were free of holes and characterized by different oxygen (O_2) and carbon dioxide (CO_2) permeability, the values of which (at the storage temperatures of 1 ± 1°C and 20 ± 1°C) are reported in Table 1.

The strawberries were stored at 1 ± 1°C and 90–95% RH for 7 days. After this cool storage, the fruits were removed and stored for 2 days at 20 ± 1°C to simulate retailer conditions.

Respiration rate of strawberry

The respiration activity of the stored strawberries was obtained by the measure of the production of carbon dioxide ($RRCO_2$) and the consumption of oxygen (RRO_2) with a gas chromatograph (GC Varian 450, Italy) equipped with a capillary column (Molsieve 5A PLOT 30 μm × 30 m × 0.53 mm) and a TCD detector. The two gas rates (expressed as mmol/kg/h) were respectively calculated following the equations of a permeable system as described by Beaudry, Cameron, Shirazi and Dostallange (1992) taking into account the different permeability of the film for the packaging, the surface of the packaging, the thickness of the film, the mass of the strawberry into the packaging and the difference of the partial pressure among outside and inside packaging.

Table 1. O_2 and CO_2 gas permeabilities of green films.

Tabla 1. Permeabilidad de los gases O_2 y CO_2 de los plásticos film ecológicos.

Film	Temperature (°C)	$PeCO_2$ (mmol cm/cm^2 h kPa)	PeO_2 (mmol cm/cm^2 h kPa)	$PeCO_2/PeO_2$
Control	1	6.46E − 13	2.14E − 13	3.02
	20	1.98E − 12	6.24E − 13	3.17
Film 1	1	6.64E − 13	1.70E − 13	3.90
	20	1.10E − 12	3.20E − 13	3.50
Film 2	1	7.39E − 13	1.75E − 13	4.20
	20	1.28E − 12	3.11E − 13	4.10
Film 3	1	8.71E − 13	2.03E − 13	4.30
	20	1.42E − 12	3.75E − 13	3.80

The gas permeability (mmol cm/cm^2 h kPa) was calculated using the first Fick's diffusion law.

La permeabilidad del gas (mmol cm/ cm^2 h kPa) se calculó utilizando la Primera ley de difusión de Fick.

Headspace gas composition

The changes in the CO_2 and O_2 concentrations were evaluated using a portable gas analyser (CheckPoint II, PBI Dansensor, Milan, Italy). The headspace gas compositions in the packages were measured daily throughout the trial. To avoid causing changes to the headspace gas compositions during gas sampling, the same air volume was maintained in the packages throughout the trial period by virtue of a modification made by the supplier to ensure that the analyser would introduce the same quantity of air that it removed for the analysis. To prevent gas leakage during the measurements, an adhesive septum system (silicone septum, Dansensor, Milan, Italy) was placed on the surface of the package. The results are expressed as the average of three replicates.

Measurements of weight loss and fruit quality analysis (external colour, firmness, total soluble solids and titratable acidity)

Analyses of the fruit quality and nutraceutical contents were performed for each sample at 5 time points: at harvest (0 days); after 3, 5 and 7 days of storage at a constant temperature of 1 ± 1°C and after a subsequent 2 days of shelf storage at 20 ± 1°C.

The weight loss of each strawberry basket was measured using an electronic balance (SE622, WVR, Washington, USA) with an accuracy of 0.01 g. The weight of each package was recorded at harvest and at the end of each sampling date.

The external colour was measured using a hand-held colorimeter (Chroma Meter CR-400, Konica Minolta Sensing, Inc., Tokyo, Japan) using the CIELAB scale defined by the *Commission International de L'Eclairage*, in which *L** (lightness/darkness), *a** (redness/greenness) and *b** (yellowness/

blueness) are mutually perpendicular axes. Three parameters were considered to assess the colour changes of the strawberries after 9 days of storage: brightness (L^*), Chroma [$C^* = (a^{*2} + b^{*2})^{1/2}$] and hue angle [$h = (\arctan(b^*/a^*)$].

The firmness was measured using a hand-held penetrometer (Turoni, Forlì, Italy) with a 4-mm diameter plunger in accordance with standard industry practice. The probe was pushed into the strawberry flesh through the skin to the depth of the head (5 mm) (Buckart, 1943).

A total soluble solids (TSSs) analysis was performed on squeezed strawberries at 20 ± 1°C. The TSS concentrations were determined by homogenizing ten individual fruits from each lot and recording measurements using an Atago Pal-1 pocket refractometer (Atago Co. Ltd., Japan).

The titratable acidity (TA) was measured using an automatic titrator (Titritino 702, Metrohm, Swiss) and was determined potentiometrically using 0.1 N NaOH to an end point of pH 8.0 in 5 mL of juice diluted in 50 mL of distilled water.

Nutraceutical analysis (total polyphenols and total anthocyanins)

To determine the total anthocyanin contents and the total phenolic contents of the tested samples, extracts were obtained from the strawberries by adding 10 g of fruit to 25 mL of extraction buffer (500 mL of methanol, 23.8 mL of deionized water and 1.4 mL of 37% hydrochloric acid). After 1 h in the dark at room temperature, the samples were thoroughly homogenized for several minutes using an ULTRA-TURRAX device (IKA, Staufen, Germany) and centrifuged for 15 min at 3000 rpm.

The supernatants obtained were collected, transferred into glass test tubes and stored at −80°C until analysis.

The total anthocyanin content was quantified following the pH differential method of Cheng and Breen (1991). The anthocyanin content was estimated based on the differences in absorbance between 510 and 700 nm in buffers at pH 1.0 and pH 4.5 such that $A_{tot} = (A_{515}–A_{700})$ pH 1.0 − $(A_{515}–A_{700})$ pH 4.5. The results are expressed in units of milligrams of cyanidin-3-glucoside (C3G) equivalent per 100 g of fresh weight (fw).

The total phenolic content was measured at 765 mm using Folin-Ciocalteu reagent with gallic acid as the standard, following the method of Slinkard and Singleton (1977). The results are expressed in units of milligrams of gallic acid equivalent (GAE) per 100 gp of fw.

Both of these analyses were performed using a UV–vis spectrophotometer (UV-1600PC, VWR International).

Sensorial evaluation

A descriptive analysis of the odour and appearance of the tested strawberries was performed. For the evaluation, 15 panellists (60% female and 40% male, between 20 and 30 years of age) were recruited from among students in the DISAFA, University of Turin.

The descriptors used to evaluate the sensorial attributes of the fruits, with the purpose of assessing the interactions of the different packaging materials with the strawberries, are reported in Table 2; these descriptors are based on the work of Ares, Barrios, Lareo and Lema (2009); 10 fruits/each sample were selected randomly and they were evaluated by the panellists. The off-flavour was immediately evaluated after the opening of each package.

Table 2. Determination of the attributes for the sensory evaluation of strawberry cv. Portola.

Tabla 2. Determinación de los atributos en la evaluación sensorial de las fresas cv. Portola.

Attributes	Definition
Condense	Presence of condense inside the package on the film and on the fruits
Off odour	Intensity of fermentation or other non-characteristic odours
Decay	Presence of mould or/and deliquescent fruits
Red colour	Extent of red colour on the outside
Browning of the sepal	Extent of brown colours on the sepals
Marketing	Presence of saleable fruits
Taste	Taste of the fruits during the consumption

The selected attributes were judged with white light (incandescent) at the room temperature (20 ± 1°C) at the DISAFA (University of Turin) laboratory using a 5-point hedonic scale, where 5 = optimal, 4 = good, 3 = fair, 2 = limited marketability and 1 = very bad or inedible. Five strawberries were selected at random from each package at each time point for the sensorial evaluations.

Statistical analysis

All statistical analyses were performed using the SPSS Statistics 20 statistical software package (SPSS Statistics 20, 2013, IBM, Italy) for Mac. The obtained data were subjected to two-way analysis of variance (ANOVA), and the means of the quality and nutraceutical parameters were separated using Tukey's test ($P \leq 0.05$). When the interactions were significant, the mean values were compared using a least significant difference (LSD) multiple range test, with $P < 0.05$ considered significant. For the sensorial evaluations, a principal component analysis (PCA) was performed on the mean scores assigned by the panellists to determine the relationships between the sensory attribute variables and the sample packages. The PCA was performed using standardized data.

Results and discussion

Headspace gas composition

MAP is used to achieve atmospheric levels of O_2 and CO_2 that are adequate for preserving the quality parameters of packaged fruit products by virtue of the interaction of several factors, such as the permeabilities of the films, the storage temperature and the respiratory activity of the fruits (Beaudry et al., 1992; Kader, Zagory, & Kerbel, 1989). The contributions of all these factors can be observed in the compositions of the headspace gasses inside the strawberry (cv. Portola) packages that are reported in Figure 1. With the polypropylene film (control), no change was observed in the atmosphere inside the packages throughout the entire storage time because of the macro-perforations (6 mm in diameter). All of the green films were used to wrap the packages under ordinary atmospheric conditions (21.2% O_2 and 0.03% CO_2). However, subsequent changes in these conditions were observed; in fact, in all samples, the O_2 level had decreased and the CO_2 level had increased after only

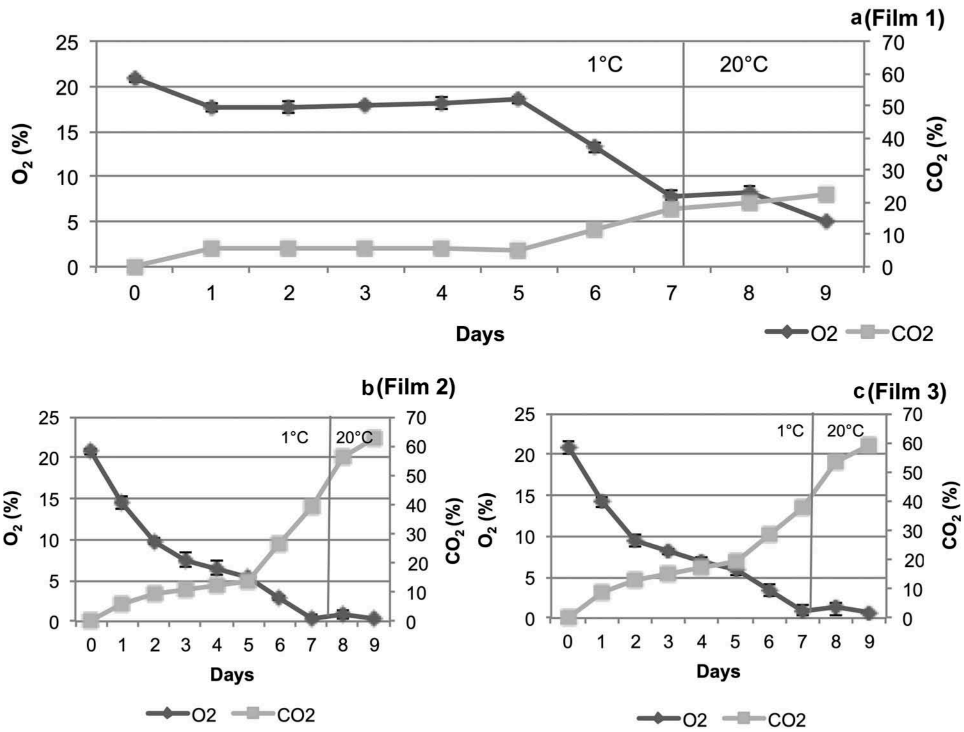

Figure 1. Evolution for the headspace O_2 concentration and CO_2 concentration of cv. Portola strawberry fruits. (a) evolution for the film 1, (b) for the film 2 and (c) for the film 3.

Figura 1. Evolución de la concentración de los gases O_2 y la concentración de CO_2 de las fresas cv. Portola. (a) evolución del film 1, (b) del film 2 y (c) del film 3.

1 day of storage. Throughout the entire storage time, all three films exhibited different behaviours regarding the achievement of a steady state (Martínez-Romero, Guilén, Castillo, & Valero Serrano, 2003; Serrano, Martínez-Romero, & Guillén, 2006). This phenomenon can be primarily attributed to the different gas permeabilities of the films (Table 1) because all other relevant factors (mass of the product, size of the packages and storage temperature) were held constant (Kader et al., 1989). For film 1 (Figure 1(a)), the equilibrium state for both gasses was achieved after 1 day of low-temperature storage (1 ± 1°C), and it remained stable for up to 5 days, corresponding to a composition of 17.60–18.50% O_2 and 5.30–5.60% CO_2. The atmospheres inside films 2 and 3 reached a steady state at 5 days at 1 ± 1°C, with compositions of 5.4% O_2/13.6% CO_2 and 5.9% O_2/19.7% CO_2, respectively.

After this time, for each film, this condition was immediately lost. In fact, a rapid decrease of O_2 and increase in CO_2 are occurred already before the 7th day when the temperature has been changed. These trends mainly detectable in the strawberries packaged with the films 2 and 3 have been generated probably due to the microbial spoilage (Figure 2). The susceptibility to decay during the cold storage was found due to the increase in the content of the moisture observed inside the packages wrapped with these films. Even if the water permeability of the films made from biodegradable sources is higher than those of traditional plastic materials (Guilbert, Cuq, & Gontard, 1997), the prototypes of films 2 and 3, in this study, have showed a barrier to the permeation of water sufficient to develop an early decay on fruits. The increase of the temperature affected both the metabolic activity of the strawberries (Table 3) and the

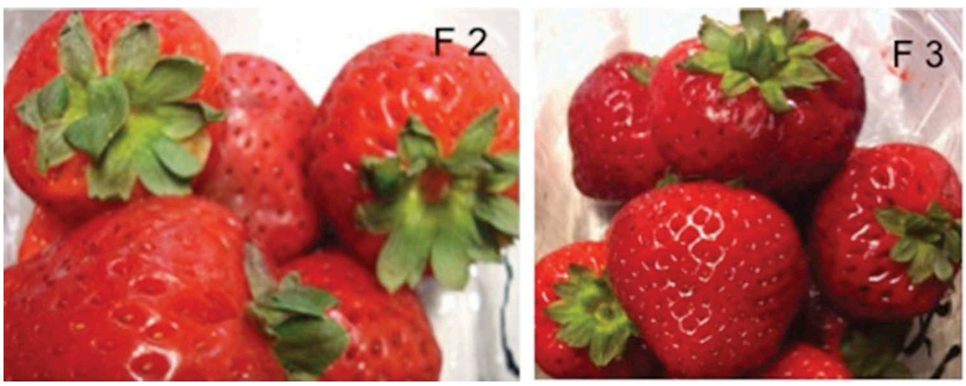

Figure 2. Initial decay after 5 days at 1 ± 1°C on strawberries stored in MAP with films 2 (F2) and 3 (F3).

Figura 2. Decadencia inicial después de 5 días a 1 ± 1°C en las fresas almacenadas en MAP con film 2 (F2) y film 3 (F3).

Table 3. Respiration rate for the O_2 (RRO_2) and CO_2 ($RRCO_2$) at the sevent (1°C) and ninth (20°C) for the films 1, 2 and 3.

Tabla 3. Velocidad de respiración de O_2 (RRO_2) y CO_2 ($RRCO_2$) al séptimo (1°C) y noveno (20°C) del film 1, film 2 y film 3.

		RRO_2	$RRCO_2$
Days	Film	(mmol/kg//h)	
7	Film 1	2.65E − 06 ± 1.50E − 07	8.64E − 06 ± 4.32E − 07
	Film 2	5.95E − 07 ± 2.40E − 07	6.70E − 06 ± 9.57E − 07
	Film 3	2.50E − 07 ± 2.47E − 08	8.09E − 07 ± 1.17E − 07
9	Film 1	3.41E − 06 ± 5.41E − 08	3.61E − 05 ± 6.80E − 06
	Film 2	4.15E − 06 ± 1.29E − 07	2.46E − 05 ± 2.69E − 06
	Film 3	3.58E − 06 ± 4.50E − 07	3.33E − 05 ± 1.16E − 05

values of the gas permeabilities of the wrapping films. Even if the CO_2 generated by the fruits ($RRCO_2$) covered with the film 1 (8.64E − 06 mmol/kg/h) is little higher than other samples (Table 3), the film 1 is the only one able to maintain for more time the steady state and the gas composition near to values suggested for MAP (Fonseca et al., 2002; Kader, 1993; Saltveit, 1993; Silva et al., 1999). This condition was possible thanks to the good selectivity ($PeCO_2/PeO_2$) of the film 1 at 1 ± 1°C and 20 ± 1°C (Table 1).

Weight loss

Weight loss during storage exerts a negative effect on the appearance of strawberry fruits, leading to shrivelling and a dull-looking epidermis. The maximum weight-loss limit for the marketability of fresh commodities is 6% (Almenar et al., 2007; Robinson, Browne, & Burton, 1975). Another important concern for minimizing the deterioration of strawberry fruits is temperature management; higher storage temperatures result in higher respiration rates and shorter storage periods, which are, in turn, associated with a loss of fruit quality (Ayala-Zavala, Wang, Wang, & González-Aguilar, 2004; Nunes, Brecht, Sargent, & Morais, 1995; Shin, Ryu, Liu, Nock, & Watkins, 2008). In our study, the weight-loss values observed for all films were below the threshold of 6%. Figure 3 shows that for all films, an increase in weight loss was observed throughout the storage time, especially during shelf storage at 20 ± 1°C. After 9 days, the highest weight loss was observed for the control (1.39 ± 0.19%), whereas the fruits packaged in the green films exhibited lower weight-loss values (0.71 ± 0.14%, 0.92 ± 0.08% and 0.69 ± 0.11% for films 1, 2 and 3, respectively). As observed for the traditional plastic films used for MAP, the green films used in this study were also able to control and limit the diffusion of water vapour, thereby reducing the transpiration rate. Nevertheless, although all samples exhibited weight losses below the recommended limit, the high CO_2 concentrations observed in the packages wrapped with films 2 and 3 (Figure 1(b,c)) caused the strawberries to be unacceptable for consumption after only 5 days of storage. In the case of the control samples, the strawberries were instead considered unsalable by retailers after 5 days because of the high dehydration resulting from the macro-perforations in the film.

Fruit quality analysis (external colour, firmness, TSSs and TA)

The effects on the quality parameters of the strawberries that were observed during storage are reported in Table 4. Based on the external colour measurements, it appears that the different films exerted no influence on the brightness, Chroma or hue angle; all of these parameters were instead merely statistically influenced by the storage time. The interaction between the films and the duration of storage affected only the hue angle. The brightness (L^*) parameter (Table 5) decreased over time during storage for all samples because the strawberries developed a darker colour as they matured after harvest, as reported by Almenar et al. (2007) and Zhang and Watkins (2005). At harvest time, the L^* value was 40.88, and at the end of storage (9 days), the measured values were 30.49, 34.20, 31.55 and 32.59 for the control, films 1, 2 and 3, respectively. At this time point, the strawberries stored under MAP conditions using film 1 showed the higher L^* value if compared with other samples.

The fruit developed a less vivid colouration during storage, as evidenced by the lower Chroma values (Hernández-Munoz, Almenar, & Del Valle, 2008; Sanz, Pérez, Olìas, & Olìas, 2000). The hue angle also evolved similarly to the other colour parameters.

The general analysis of qualitative data with the multivariate linear analysis (LSD post doc) showed as the firmness of the strawberry pulp was influenced by the film used for packaging and, consequently, by the atmosphere surrounding the product, whereas the TSS content was the only qualitative parameter to be affected by the interaction between the film and the number of days spent in storage (Table 4). Instead, analysing the pulp firmness (Table 5) at each control analysis, no statistically significant differences were observed between the packages for up to 3 days of storage, whereas after 5 days of storage, all of the MAP

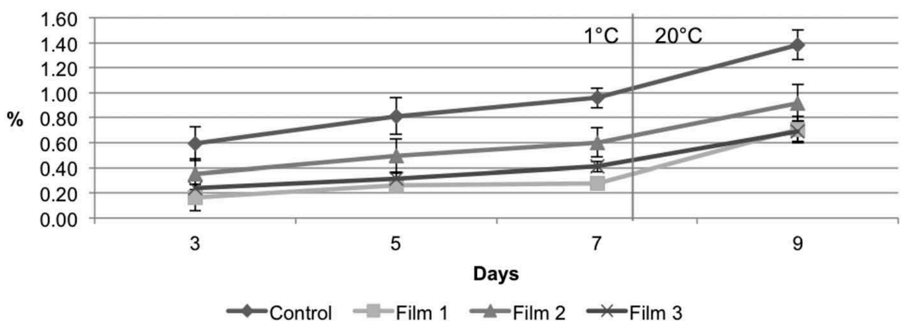

Figure 3. Weight loss (%) of cv. Portola strawberry fruits stored for 9 days.

Figura 3. Pérdida de peso (%) de las fresas cv. Portola almacenadas durante 9 días.

Table 4. Multivariate linear analysis for colour parameters (L^*, C^*, °h), firmness (g/cm^2), total soluble solid (TSS) (°Brix), citric acid (%) of strawberry cv. Portola.

Tabla 4. Análisis lineal multivariado de los parámetros de color (L*,C*, °h), la firmeza (gr/cm^2), el total de sólidos solubles (TSS) (°Brix) y el ácido cítrico (%) de las fresas cv. Portola.

LSD	Brightness	Chroma	Hue	Firmness	TSS	Citric Acid
Film	0.10	0.29	0.99	0.03	0.02	0.00
Days	0.00	0.00	0.01	0.28	0.00	0.00
Film × Days	0.42	0.08	0.00	0.06	0.00	0.20

When interactions were significant, the mean values were compared by a least significant difference (LSD) multiple range test with $P < 0.05$ considered significant.

Cuando las interacciones fueron significativas, los valores promedio se compararon con las diferencias menos significativas (LSD) del test de rango múltiple con P < 0,05 considerado significativo.

samples (films 1, 2 and 3) showed a rapid decrease in pulp firmness compared with the fruits stored in air (control). These results could be attributed to the development of spoilage observed (data not showed), and they are consistent with data from a previously published study, in which fruits stored under CO_2 and normal atmosphere exhibited similar softening values (Del Rio, Martinez-Javega, Navarro, & Mateos, 1987). The ratio between the sugars and organic acids contained in strawberries determines their taste. Sucrose, glucose, fructose, citric acid and malic acid are among the most important flavour components in strawberries (Kader, 1991; Pérez & Sanz, 2008). The TSS value at harvest time (0 day) was 6.82°Brix (Table 5). Because of the slight weight losses that occurred during storage, all samples exhibited an increase in TSS, as reported in previous studies (Giuggioli, Girgenti, Baudino, & Peano, 2014; Peano, Girgenti et al., 2014; Peano, Giuggioli et al., 2014).

As shown in Table 4, the citric acid content was statistically influenced by the film type and the storage time. The total acidity is expressed in terms of the total quantity of citric acid (%) because this is the predominant organic acid present in strawberries (Holcroft & Kader, 1999). At harvest, the citric acid content was 0.89% (Table 5), and for all samples, a subsequent decrease in this value was observed, consistent with Ke, Goldstein, O'Mahony and Kader (1991); the evolution of this qualitative parameter was most strongly affected by the change in the storage temperature from 1 ± 1 to 20 ± 1°C after 7 days.

Nutraceutical analysis (total polyphenols and total anthocyanins)

Table 6 reports the effects of the film type, the storage time (days) and the interaction between these two factors on the total polyphenol content and the total anthocyanin content

Table 6. Multivariate linear analysis for total polyphenols (mg$_{GAE}$/100 gp) and total anthocyanins (mg$_{C3G}$/100 gp) of strawberry cv. Portola.

Tabla 6. Análisis lineal multivariado del total de polifenoles (mg$_{GAE}$/100gp) y el total de antocianinas (mg$_{C3G}$/100gp) de las fresas cv. Portola.

LSD	Total polyphenols	Total anthocyanins
Film	0.68	0.30
Days	0.34	0.10
Film × Days	0.94	0.74

When interactions were significant, the mean values were compared by a least significant difference (LSD) multiple range test with $P < 0.05$ considered significant.

Cuando las interacciones fueron significativas, los valores promedio se compararon con las diferencias menos significativas (LSD) del test de rango múltiple con P < 0,05 considerado significativo.

Table 5. Changes in colour parameters (L^*,C^*, °h), firmness (g/cm^2), total soluble solid (TSS) (°Brix), acid citric (%) of strawberry cv. Portola.

Tabla 5 Cambios en los parámetros de color (L*,C*, °h), la firmeza (gr/cm^2), el total de sólidos solubles (TSS) (°Brix) y el ácido cítrico (%) de las fresas cv. Portola.

		Days													
		0		3			5			7			9		
Brightness (L^*)	Control	40.88	β	37.90	ns	β	37.20	a	α	35.90	ns	β	30.49	b	β
	Film 1		α	37.98		αβ	35.62	ab	βγ	35.32		βγ	34.20	a	γ
	Film 2		ns	37.73			33.85	b		34.72			31.55	b	
	Film 3		α	35.73		β	35.82	ab	β	34.65		β	32.59	ab	β
Chroma (C^*)	Control	52.88	α	48.08	ns	α	48.91	a	α	41.74	b	β	40.69	ns	β
	Film 1		α	47.58		β	45.78	b	β	50.11	a	αβ	39.65		γ
	Film 2		α	50.49		α	44.92	b	βγ	45.26	b	β	41.42		γ
	Film 3		α	49.48		αβ	45.92	b	βγ	45.37	b	γ	43.98		γ
Hue (°h)	Control	0.68	α	0.58	ns	αβ	0.59	a	αβ	0.51	ns	β	0.58	ns	αβ
	Film 1		α	0.59		β	0.57	a	β	0.56		β	0.53		β
	Film 2		α	0.59		α	0.50	b	β	0.53		αβ	0.51		β
	Film 3		α	0.56		β	0.56	a	β	0.56		β	0.54		β
Firmness (g/cm^2)	Control	0.96	α	1.06	ns	α	0.94	a	α	0.62	ns	β	0.57	a	β
	Film 1		α	1.06		α	0.50	b	β	0.57		β	0.57	a	β
	Film 2		α	1.00		α	0.59	b	β	0.59		β	0.56	a	β
	Film 3		α	0.96		α	0.60	b	β	0.57		β	0.43	b	γ
TSS (°Brix)	Control	6.82	ns	8.82	a		7.41	b		7.86	ns		8.59	b	
	Film 1		β	7.47	bc	αβ	8.80	a	α	7.46		αβ	8.51	b	α
	Film 2		β	6.59	c	β	7.96	ab	α β	7.54		α	8.62	b	α
	Film 3		γ	7.64	b	γβ	8.02	ab	γβ	8.49		αβ	9.41	a	α
Acid citric (%)	Control	0.89	α	0.80	a	β	0.84	A	β	0.70	a	γ	0.68	a	γ
	Film 1		α	0.66	b	β	0.69	b	β	0.65	a	β	0.65	b	β
	Film 2		α	0.80	a	β	0.72	c	γ	0.63	ab	δ	0.60	c	δ
	Film 3		α	0.65	b	β	0.64	d	βγ	0.60	b	γδ	0.56	d	δ

a–d: The means in a column followed by different letters are significantly different at $P \leq 0.05$ according to Tukey's test.

α–γ: The means in a row followed by different letters are significantly different at $P \leq 0.05$ according to Tukey's test.

a–d, Los promedios en una misma columna seguidos por distintas letras son significativamente diferentes a p ≤ 0,05 según el test de Tukey.

α–γ Los promedios en una misma fila seguidos por distintas letras son significativamente diferentes a p ≤ 0,05 según el test de Tukey.

Table 7. Changes in total polyphenols (mg_{GAE}/100 gp) and total anthocyanins (mg_{C3G}/100 gp) of strawberry cv. Portola.

Tabla 7. Cambios en el total de polifenoles (mg_{GAE}/100gp) y el total de antocianinas (mg_{C3G}/100gp) de las fresas cv. Portola.

		Days									
		0		3		5		7		9	
Total polyphenols	Control	172.79	ns	179.83	ns	190.34	ns	178.89	ns	172.74	ns
	Film 1		ns	181.38	ns	140.70	ns	198.71	ns	172.79	ns
(mg_{GAE}/100 gp)	Film 2		ns	209.05	ns	200.65	ns	186.48	ns	167.17	ns
	Film 3		ns	194.83	ns	180.97	ns	184.57	ns	180.77	ns
Total anthocyanins	Control	29.44	α	12.70	β	16.35	β	21.51	α β	18.27	β
	Film 1		ns	15.55	ns	14.60	ns	20.06	ns	20.02	ns
(mg_{C3G}/100 gp)	Film 2		α	15.27	β	14.32	β	15.99	β	16.04	β
	Film 3		α	15.13	β	14.34	β	14.74	β	15.40	β

α–γ: The means in a row followed by different letters are significantly different at $P \leq 0.05$ according to Tukey's test.

α- γ Los promedios en una misma fila seguidos por distintas letras son significativamente diferentes a p ≤ 0,05 según el test de Tukey.

in the tested strawberries. No effect of the film type on the total polyphenols evolution was observed, nor did the storage time or the interaction between these factors influence the evolution of these compounds. As shown in Table 7, the total polyphenol content at harvest was 172.79 mg_{GAE}/100 gp, and no statistically significant differences were reported, either between different treatments at the same time point or between different time points for the same treatment. Elevated CO_2 concentrations can cause a decrease in polyphenols in various fruits (Gil, Tudela, Marín, & Artés, 1995; Lin, Koehler, & Shewfelt, 1989), but few studies have addressed this effect in strawberries (Gil, Holcroft, & Kader, 1997). The CO_2 concentrations measured in the MAP samples prepared using the biodegradable and compostable films seemed to have no effect on the evolution of the total polyphenols. In fact, the polyphenol content also was not affected by the storage conditions, remaining stable even with the change in the storage temperature from 1 ± 1 to 20 ± 1°C after 7 days, consistent with Cordenunsi et al. (2005).

Similarly, in the case of the anthocyanin content, as well, the film type, the storage time and the interaction between film type and storage type did not significantly affect (Table 6) the evolution of these nutraceuticals compounds. The initial anthocyanin content was 29.44 mg_{C3G}/100 gp, and no statistically significant differences were observed between the different packages at any time point. The destabilization of these phytochemicals in strawberry juice under different storage and atmospheric conditions has previously been reported (Fabroni, Amenta, Timpanaro, & Rapisarda, 2010); in our case, the degradation of anthocyanins was observed in all packages except in the case of the fruits wrapped with film 1. The highest CO_2 concentrations were observed for films 2 and 3 (Figures 1(b,c)), confirming previous results (Almenar et al., 2007; Ke et al., 1991). In fact, CO_2 treatment may induce anthocyanin degradation and/or inhibit postharvest synthesis. These results are supported and confirmed by the brightness values measured at the end of storage (9 days), as reported in Table 5.

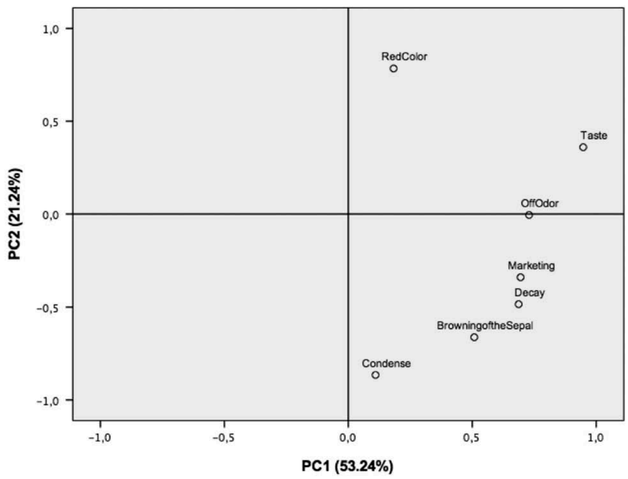

Figure 4. Factor loadings on the principal component analysis of the data from the consumer test descriptive analysis of the strawberry with different sensory quality.

Figura 4. Factores de proporción del análisis de componentes principales de los datos del análisis descriptivo de la prueba a los consumidores acerca de las fresas con calidad sensorial distinta.

Table 8. Evolution for the sensory evaluation for control and film 1 during all the storage time.

Tabla 8. Evolución de la evaluación sensorial del plástico control y el film 1 durante todo el tiempo de almacenamiento.

		Days			
Film	Attributes	3	5	7	9
Control	Condense	5.00	5.00	5.00	4.00
	Off odour	5.00	5.00	5.00	4.00
	Decay	5.00	5.00	3.67	2.33
	Red colour	3.33	3.20	3.00	2.67
	Browning of the sepal	4.50	4.83	4.50	3.50
	Marketing	3.83	3.17	3.00	1.67
	Taste	3.50	3.16	3.00	1.33
Film 1	Condense	5.00	5.00	5.00	4.00
	Off odour	4.67	5.00	5.00	3.67
	Decay	5.00	5.00	4.67	2.67
	Red colour	4.67	4.33	3.66	3.58
	Browning of the sepal	4.67	4.50	4.83	3.00
	Marketing	3.88	3.83	3.16	2.00
	Taste	3.50	3.50	3.27	2.67

Sensorial evaluation

Sensorial evaluations were performed only on consumable samples (control and film 1). A PCA of the correlation matrix generated from the ratings assigned by the panellists to the fruits packaged in each film at each storage time, across all attributes, was conducted (Figure 4). The first two principal components accounted for 53.24% (PC1) and 21.24% (PC2) of the variance of the data. PC1 and PC2 represent positive ratings by the panellists in terms of redness, taste and off odour, whereas decreased marketability, browning of the sepals and condensation in the packaging influenced the panellists' choices positively in the case of PC1 and negatively in the case of PC2. In Table 8, the average score assigned by the panellists is reported for each attribute at each time point. Generally, the highest scores for all attributes were assigned to the control and film 1 samples stored at the lower storage temperature (1 ± 1°C). The scores for the taste and redness attributes were higher for the film 1 samples than for the control samples at each time point.

Conclusions

The choice of green films for use in fruit packaging is of fundamental importance for promoting sustainability in the development of MAP technology for the post-harvest sector. The changes in temperature that occur throughout the supply chain and the gas properties of the films are the main factors that must be considered in the management of products stored under MAP conditions.

All of the green films that were tested in this study were able to modify the atmosphere inside the packages, but film 1 was able to reach the steady-state point before the other films and to maintain this equilibrium for the majority of the storage time.

This behaviour is fundamental for preserving the qualitative and nutraceutical parameters of perishable fruits. In the sensorial evaluation, the panellists preferred the samples packaged using film 1 to those packaged using the control, which suggests that this film may be suitable for use in MAP applications. During the fruit-packing process, all of the green films demonstrated good machinability comparable to that of the traditional plastic films used in a warehouse context (polypropylene), which is an important technical standard for the evaluation of such films for their potential use in the post-harvest supply chain.

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